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ABSTRACT

This paper describes a program sponsored by Dartmouth's Thayer School of Engineering for high school science and mathematics teachers that includes an intensive summer workshop, post-workshop consultation and communication with the Thayer School staff and other past participants, and materials development. The program offers teachers a framework wherein their students develop problem-solving skills that require critical thinking, communication, and teamwork. Within this framework, students are given the opportunity to defend their own problems and develop solutions to those problems. Students make testable predictions and analyze test results, encounter the real world in their search for answers, take into account ideas from a variety of disciplines, and communicate their findings both in a traditional written format and orally to a review board of professionals in the field. While developing new skills and learning to trust their own judgment, students also accomplish highly technical tasks and develop solid expertise in their field of inquiry. Also discussed is the project's dissemination beyond Dartmouth through workshops composed and run by past participants in this program. (DDR)

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Engineering Concepts in the High School Classroom:

The Dartmouth/Thayer Problem-Solving Methods

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Abstract

In the early 1960s, the introductory course in engineering offered at Dartmouth's Thayer School of Engineering was re-designed to focus on the introduction and implementation of problem-solving strategies used by engineers in practice. In 1990, having determined that this course would find great interest among K-12 educational practitioners, we encapsulated it into a program for high school science and math teachers. "Engineering Concepts for the High School Classroom" includes an intensive summer workshop, post-workshop consultation and communication with Thayer School staff and other past participants, and materials development. The program offers teachers a framework wherein their students develop problem-solving skills requiring critical thinking, communication, and teamwork. Within this framework, students are given the opportunity to define their own problems and develop original solutions to those problems. They make testable predictions and analyze test results, encounter the real world in the search for answers, take into account ideas from a variety of disciplines, and communicate their findings both in a traditional written format and orally to a review board composed of professionals in the field. As students develop new skills and learn to trust their own judgment, they also accomplish highly technical tasks, giving them solid expertise in their field of inquiry.

This paper describes the program and its methods, provides examples of high school classroom results, and discusses its dissemination beyond Dartmouth through workshops composed and run by past participants in this program.

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Introduction

The last decade has seen a great deal of concern and attention focused on the need to improve teaching and learning, particularly in K-12 science and mathematics education. Standards developed by the American Association for the Advancement of Science, the National Research Council, and the National Council for Teachers of Mathematics emphasize problem solving and real-world connections [1]. Teachers eager to implement the standards often are stymied in their search for a framework that not only allows students to immerse themselves in solving problems they care about but also subjects them to the rigors of scientific inquiry. In the "real" world, business leaders seek workers who can ask probing questions, work effectively in teams, communicate ideas effectively, and bring a project to a successful conclusion.

What does the engineering design cycle have to do with K-12 education reform? A growing number of teachers interested in responding to the calls for reform of secondary science and mathematics education have found a very useful set of a tools in a rather unexpected place – a small engineering school in northern New England. In the early 1960s, the introductory course in engineering offered at Dartmouth's Thayer School of Engineering was re-designed to focus on the introduction and implementation of problem-solving strategies used by engineers in practice. Since 1990, Thayer School of Engineering at Dartmouth College has offered an intensive, seven-day summer workshop based on this course for 24-28 high school science and math teachers. It allows them first to experience engineering problem-solving techniques, and then to develop plans to incorporate those techniques into their own curricula. Related activities include the development of instructional materials using a variety of media, and a growing network of teachers using the problem-solving methods in secondary teaching.

History of the Program

The "Engineering Concepts for the High School Classroom" program is now in its sixth year. It began with an intensive summer workshop in 1990, based on the results of a 1989 planning workshop and focus group with high school science and math teachers, exploring their interests and needs, and ways in which an engineering school might serve them. In 1993, a grant from the National Science Foundation funded the program's expansion to include more post-workshop communication and collaboration among teachers, and an external evaluation of the program's effectiveness in improving secondary science and mathematics education. To date, 155 teachers from 38 states have attended the workshop.

Curriculum

The engineering problem solving approach, particularly as taught in Thayer School's introductory design course, developed over the last thirty years, represents a distinctive pedagogical strategy which mimics the actual practice of engineering. At once highly structured and open-ended, it offers a framework for integrating several disciplines while maintaining the rigors of scientific inquiry. Like engineers in the real world, teams of students work on projects which synthesize science, mathematics, technology, economics, management, and communication. Each team applies engineering analysis and experimentation to a laboratory or real-world problem—one which team members themselves have identified—by designing and constructing a prototype of a unique device or process. As they move through a problem-solving cycle, not only the scientific

and/or mathematical requirements of the problem are considered, but also social, economic, environmental, and ethical effects and issues.

In the college-level course, students are given a very general theme and are asked to develop a product or device which addresses a real, unmet need in the marketplace. To meet this challenge, students work in teams and must undertake patent searches, design, build, and test a working prototype, develop business and marketing plans, successfully communicate their ideas orally and in writing to an external review board, document their work, and work effectively as a member of a team. As they plan and develop the actual device, students frequently need complex mathematical tools and scientific knowledge. To meet these needs, they learn to access resources — expertise, information, literature, equipment and materials — from a wide variety of sources. In the process, they also learn to be creative, to take risks, and to think in an entrepreneurial fashion. There is no textbook for this approach. Instead, there is a very specific framework for the process. It begins with the problem statement, then considers re-statement of the problem, specifications, brainstorming, analysis of alternatives, specifications for choice, fabrication and testing, and test of fitness.

In the summer workshop, teachers experience a short version of this course, and then consider its appropriate adaptation for their classrooms. Teachers working in teams of four spend the first half of the seven-day session experiencing the various steps of problem-solving as they build a working prototype of a new product. They learn how to:

- segment the vast realm of possible problems
- re-define a problem to avoid bias in designing its solution
- generate multiple alternative solutions
- research existing products which address the need
- identify the parameters, constraints, and other specifications for a successful solution
- assess the effectiveness of possible solutions based on those parameters, and
- select one which appears optimal for addressing the problem.

Workshop participants are given access to resources: libraries, shops, and a small budget, and they are encouraged to rely on the vast range of resources available in the public domain as well as on campus in terms of people and expertise. In using the framework, they employ brainstorming techniques, use matrices to analyze potential solutions, and finally present their solutions both in writing and orally to a review board.

During the second half of the workshop, teachers design curriculum for use in the classroom based on the problem-solving methods. While they are typically highly enthused about their experience in the hands-on design process, they initially are often skeptical about applications to their own classrooms. During the process of designing curriculum, however, they begin to break away from their own preconceptions of constraints. Past participants present results from testing use of the problem-solving methods in their high school classrooms. Throughout, a great deal of discussion, information and ideas, and networking among the group's diverse participants, who teach in schools large and small, urban, suburban, and rural, private and public, in states all across the nation, elevates the level of exchange.

During the last five years, this process has been adopted for use in high school classrooms across the country. Each teacher provides a broad set of criteria for selecting

a project, but the students generally choose their own project. As students move into areas in which they lack expertise, they gather information by asking questions—of their teachers and other school staff, of mentors from the business and professional worlds, of community members or others who might use their device, of technicians in corporations who use similar technologies. Working together and individually, students learn to trust their own judgment, and develop an appreciation for how science and mathematics are applied in the real world. Evaluation of student work is accomplished through written papers and oral presentations. A range of community members—district administrators, school board members, professional engineers, business people—serving as a review board, judge the merits of each project against criteria drawn up by the teacher.

The summer workshop has been developed jointly by the authors. Professor Collier, who has taught the undergraduate "ENGS 21 – Introduction to Engineering" course at Dartmouth for a decade, is the primary workshop instructor. Associate Dean Muller has developed and oversees all aspects of organization for the workshop and its attendant activities.

Examples of Implementation in High School Classrooms

Why does this approach interest science and math teachers? Because engineering is fundamentally an applied field and its products affect everyday life, a focus on engineering can be an effective and exciting way for students to learn about science. Students are far more motivated, and will work harder and learn better, when the problem they are working on is one they have selected. Teachers experience the problem-solving approach as a challenging, but exhilarating experience themselves. The synopses below give a few examples of results of using these methods.

Three teachers in Colorado Springs – a math teacher, a physics teacher, and an industrial arts teacher, two of whom attended the workshop in 1990, collaborated to persuade their district to adopt a new schedule. It allowed them to establish their assigned class periods consecutively, for a block of 2-1/2 hours each day for a project-based class integrating math, physics, and "hands-on" design and building. This project, called STEM ("Science, Technology, Engineering, and Mathematics") later resulted in the award to one of the teachers of the Toyota Tapestry Award.

A physics teacher who had worked with students for four years in the national Duracell Device contest attended the summer workshop. After becoming acquainted with the engineering problem-solving cycle, he found his students could overcome roadblocks against which they had previously stumbled time and time again. His students went on to become finalists in the competition in 1991, which had never happened before. This success continued, with six national winners in 1992, and the 2nd place winner nationally in 1993 plus other award winners.

A Hanover, New Hampshire teacher created a new, year-long course incorporating advanced physical sciences concepts into a completely project-based curriculum, drawing on the example of ENGS 21. Each year, teams of students from the course enter the University of Vermont Design Competition. In 1994, one of the teams won first place. In the fall of 1995, a team of 9th grade teachers at Hanover High will implement a pilot program integrating the curriculum across five subject areas – mathematics, introductory physical sciences, social studies, English, and French – prompted by the inspiration of the new course and drawing upon the developed expertise of the original teacher.

A Boston, Massachusetts teacher used the engineering problem-solving techniques with a class, focusing on energy conservation. A group of students evaluated the school's

lighting system, and proposed a change, shortly thereafter adopted, which reduced electrical consumption for lighting by 50%.

A Bethesda, Maryland teacher created a new course, "Research Methods and Scientific Writing," drawing upon the engineering problem-solving methods. It utilized school technology staff as well as nearby university resources for patent searching.

A Niskayuna, New York teacher had students consider the problem of fumes from idling buses being drawn into the school library in the air exchange system, causing illness. The students researched the problem thoroughly using the engineering problem-solving methods and suggested reversing the fans on the air exchange system. The following year, after study and evaluation by the school administration and OSHA, engineers hired by the school district reversed the fans in the air exchange system.

A Conroe, Texas teacher wrote of her experience in teaching using the engineering problem-solving methods. "This approach has been beyond my wildest dreams. Two of the strongest rewards have been the students not losing their excitement for their work and the momentum increases with each phase of the project implementation. The creative processes of the students were exciting to share with the students and administrators. Students have included parents and community and have gone outside their immediate area to seek expertise and data."

A Los Angeles, California teacher working with inner-city students found the engineering problem-solving methods engaged their attention, and prompted higher achievement, to a much greater extent than traditional methods.

A Corcoran, California teacher with a high proportion of children of migrant workers in her school, found the engineering problem-solving methods engaged her students with real problems in the community. They were encouraged to draw upon many local resources, and produced work of unusual quality and depth.

Numerous other examples abound. As our experience with the program for high school teachers grows, so do their contributions to it. As they experiment and refine methods used in their teaching, their experiences are incorporated into program improvements, and added to materials.

Evaluation

An outside evaluator, William S. Carlsen, a science education specialist at Cornell University, recently completed an in-depth survey of past participants, including written instruments, site visits, and systematic telephone interviews of a random sample of teachers. Professor Carlsen's principal finding is that "the first-order impact of the workshop is substantive and widespread." He found 75% of the 1993 workshop participants have fully implemented the Dartmouth/Thayer problem-solving methods. That is, students constructed an actual device, and used most of the other design features specified in the problem-solving framework. The majority of teachers planned to either maintain or expand their workshop-derived projects in the coming year, and could show concrete details on planned changes. Carlsen also collected data providing concrete, if still limited, evidence that the these problem-solving methods can be successfully used with historically underrepresented and underserved groups.

In addition to helping participants bring the engineering approach to problem solving into their classrooms, the program asks participants to provide in-service training to others. 1993 workshop participants conducting in-service training within 16 months of attending the workshop reached an additional 974 teachers. The program evaluation found that 75% of the workshop graduates sampled had conducted in-school and district-wide teacher workshops, workshops for science fair mentors, college seminars,

and presentations at professional conferences, and had written articles for professional journals.

Supporting Materials

A resource manual has been developed to assist participants in both their classroom preparation and their in-service training work. Compiled by Project Writer Ellen Frye, the handbook, "A Resource Manual for Engineering Concepts in the High School Classroom," provides an overview of the educational philosophy framing the approach, details the implementation process for both the classroom work and in-service training workshops, and provides modules for project work developed and tested by teachers in a variety of different classroom disciplines and situations. A book, also written by Ellen Frye, and tentatively titled "ENGS 21: Powering Education Into the 21st Century" is currently in draft form. Written for secondary teachers and others interested in understanding the advantages of the problem-solving framework applied in teaching who have not attended the workshop, this book expands the handbook by describing a large number of successful projects as well as profiling business and professional leaders who have applied the precepts of engineering problem solving in their professional lives. A thirty-minute video, produced by David Nelson and associates at Education Development Center, Inc., will serve to introduce interested teachers and others to the problem-solving methods and their implementation in actual high school classrooms.

Conclusion

The engineering design cycle, with an explicit problem-solving framework, appears to have benefits for the enhancement of secondary science and mathematics education. To the extent that this methodology can be transferred successfully to the pre-college level, it is likely to improve student understanding of the relationships between science and mathematics and their applications in addressing real problems. The creative problem-solving process also develops important skills for productive citizens in our society, encouraging initiative, creativity, responsibility, teamwork, resourcefulness, and self-reliance. Moreover, while this new kind of teaching and learning can be challenging and difficult, it is also fun.

The next challenge is to find means of expanding the understanding and use of the engineering problem-solving approach in education. We will continue to develop materials for wider dissemination, are exploring the use of electronic communications and publishing for further communication and dissemination of the methods, and would like to identify other college and university faculty interested in exploring the possibility or replicating the workshop on their campuses to reach additional teachers.

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